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Welcome everyone to the NOAA Central Library. I am happy to announce that our presentation is going to be by Dr. Jessica N. Cross. She is from the Pacific Marine Environmental Laboratory that focuses on ocean acidification monitoring and research in the Pacific Arctic and along the Alaskan coasts. She is particularly interested in the development of new technology and techniques that reduce the cost of collecting data over the expansive and remote Arctic region. -- please join me in welcoming her.

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SLIDE 1: Thank you for coming. This presentation is meant for a variety of audiences. There are some parts directed to scientists, and parts that are directed to policy makers and local communities making decisions in their own backyard. I feel that as a scientist, it is part of our job to make sure we hit all of these different points. I hope everything you hear today is accessible, regardless of your background. It should be easily understandable. If you have questions, please type them into the Go-to-webinar chat section. We will take questions at the end.

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SLIDE 2: I will briefly start with an explanation of ocean acidification. We have seen an increase in atmospheric CO<sub>2</sub> levels since the Industrial Revolution, and this plot shows the data from the last five years.

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SLIDE 3: Approximately one third of that atmospheric carbon dioxide is absorbed by the ocean. On top of that, Alaskan waters are naturally very high in carbon dioxide. So, even when you add a little bit of human caused carbon dioxide, because the natural CO<sub>2</sub> concentration is high it causes big changes in ocean chemistry very quickly. The picture I am showing in the lower right-hand corner has a bunch of small fishing boats spelling 'SOS' with 'acid ocean' in the middle. It is from local fisherman participating in Whale Fest, an environmental advocacy event that happens every year. I want to add that Ocean Acidification is not turning the ocean acidic. It is making it more acidic than it was before. We are having acidic ocean events. That is an important distinction to make, which is why I have added the word "Events" to the picture.

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SLIDE 4: OA is an ecosystem concern because it can impact the ability of marine organisms to build and maintain shells, tests, and skeletal structures made from calcium carbonate. Even the early pH decline that we can currently see in Alaska is causing carbonate minerals to start dissolving. Low pH is corrosive, even to carbonate minerals at pH above seven or neutral. This particular slide is showing the excess amount of carbonate in the water column that has been produced as a result of this acidification. These are observations that we have already documented in Alaskan waters.

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SLIDE 5: This could have big implications for the state of Alaska. First of all, Alaska is home to 60 percent of the US fishery by weight. These commercial fisheries form a big part of the state economy, and part of the national economy as well. The pH-mediated carbonate dissolution I showed on the last slide is taking place in areas that we know are inhabited by lucrative fisheries, including red king crab and blue king crab species.

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SLIDE 6: On top of affecting commercial industry in Alaska, these acidification driven ecosystem changes could threaten food security for many of the local communities that rely on local protein and local fishing.

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SLIDE 7: I have already mentioned that ocean acidification impacts shellfish. Here, I'm showing the life cycle of the crab. We will start out with the adults. Ocean acidification creates stress for adults, and as a result there are fewer embryos and fewer larva hatching. The larva that do hatch do not necessarily survive, or a much lower percentage survive their juvenile stage. Those that do survive become stressed adults, and it starts the cycle over again. As you can imagine, this can result in a population decline.

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SLIDE 8: We know that ocean acidification also impacts fish. Rather than a specific physiological development of fish, in particular ocean acidification affects their behavior, which this infographic highlights with the magnification glass. OA interferes with sensory signals for some fish. We will talk about what that means later. Ultimately, it interferes with avoidance. They are not able to avoid predators or find prey. Which you can imagine affects their health quality.

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SLIDE 9: We also know that ocean acidification impacts the food chain. Pteropods are an important food source for many fish, including pink salmon, and pteropods are particularly vulnerable to ocean acidification. We think of them as the OA poster child. On the left, this is a healthy pteropod shell and has been exposed to ocean acidification levels that you would expect to see in the are in the year 2100. As exposure continues, what first happens is the shell pits and then starts to lose mass. We know this is already happening in places around the ocean. It is not just a lab experiment showing it might happen. Pteropod shell degradation is has been observed

off the US west coast and Antarctica. The same processes are probably happening in Alaska, even though we have not collected the data yet.

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SLIDE 10: The number one question I get at this point, regardless of who I am talking to, is: So what can we do? As a scientist, I am good at communicating what is going on in the environment. I am good at understanding the risks associated with those changes in the environment. I am not necessarily great at going beyond that [*SEE SLIDE ANIMATION*]. Having seen just a limited number of these slides, the community says I believe you, tell me what to do next. And that work that is a part of the ocean acidification portfolio too, which is where I drew this figure from.

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SLIDE 11: NOAA also participates in producing the U. S. climate resilience toolkits. These are essentially a set of online of resources that say if you and your community are concerned about climate change, here is what you can do. Each local or regional case emphasizes a resilience cycle: Start with understanding hazards and assessing risks facing your community. After that, investigate options, plan the action you may take and ultimately, take action to build resilience... which sometimes includes additional expiration, leading back to the start of the cycle. The rest of this talk will be framed in this climate resilience cycle.

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SLIDE 12: Step one, explore hazards. I have shown you a small sampling of what the OA data looks like in Alaska. I also want to go into that in more depth. In order to make these observations and to understand the duration, intensity, and extent of the spatial variability of ocean acidification, we need to be able to build an OA observing network. We do that by trying to understand what is happening over time, which we do by collecting time-series measurements. These are very helpful, but they are often geographically limited to one spot. So we also try to go out and understand what is happening in terms of space. We want to build a system that works in time *and* space.

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SLIDE 13: We do that using a variety of different platforms. We use ships, moorings, gliders and drones. In this figure, ship-based sampling is shown by the black dots. The red triangles are moorings. The gliders and drones are the gray tracks that cover most of the Alaskan coast. Alaska is very big, home to more coastline than the East Coast, West Coast, Gulf of Mexico and Great Lakes combined. On top of that, the shelf for the region is extremely wide. This creates a lot of territory for us to be able to cover. It is hard to do that.

We want to make sure we are building an observing system that meets the challenges posed by remote locations and harsh conditions. In this expansive area, we do our best to cover all of our bases. We are able to do that by using a portfolio of tools. Using all the tools in our toolbox. [*SLIDE ANIMATION*] The last key tool in the toolbox are our partners. OA research is not something NOAA does by itself. We have key partners. [*SLIDE ANIMATION*] In particular the

University of Alaska Fairbanks Ocean Acidification Research Center. They have a ton of work they have conducted through their operations. On top of that, [SLIDE ANIMATION] we work with small businesses. Small hatcheries, tribes etc. to monitor ocean acidification conditions at shore-based stations. [SLIDE ANIMATION] We have had the opportunity to work with the Alaska Marine Highway to collect more data that we can with our own ships.

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SLIDE 14: Using this portfolio of tools so far has been really successful. In 2014, this observing team won a Silver Medal for Exceptional Service to the Department of Commerce. We are proud of it. We used six different types of technology effectively to track glacial melt water coming out of this fjord and Prince William Sound and moving down the coast. It was not something that had been observed before. We were able to do it by deploying this portfolio of diverse tools.

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SLIDE 15: On top of that, we work hard to make sure we can extend our observations as much as we can. By combining the data from the moorings and ships, we can make inferences about spatial and seasonal variability around the coast. These plots show a seasonal cycle of ocean acidification variables at the three sites: one in Southeast Alaska, one at a site outside Seward, and one off of Kodiak. One of the most common variables we use for studying OA is called the calcium carbonate saturation state, often symbolized as Omega. A low omega value indicates the potential for calcium carbonate to dissolve. A shorter way of saying that is that a low omega value indicates corrosive water. These plots show a seasonal cycle of omega, with some seasons exhibiting very low values, or the presence of corrosive conditions.

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SLIDE 16: Step two, once we have observed what is going on in the environment,, we want to understand what will happen as well. What will ocean acidification look like in the future? And how will the ecosystem respond? We work closely with colleagues in the national Marine fisheries service to understand the direct impact on the organisms. That is Bob Foy working with a crab. We want to understand the chemical data and biological response data into regional models to help us fill in the gaps in time, space so that we can understand what is happening, rather than just small periods.

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SLIDE 17: What we know from current studies that ocean acidification is likely to get worse. We will start at the broad end of the modeling scale and move out to a finer scale. This particular model is based on a global model. It shows at the top, 2012. The cool colors indicate water that is acidified more than it is not. On an annual average, the water exhibits corrosive conditions. As we move down to 2050, the cool colors have spread by quite a large margin. Covering most of the Chukchi Sea. By 2100, most of the surface waters along the Alaskan coast are experiencing annual acidification. [SLIDE ANIMATION] We also worked hard to make the projections using our moorings. It is another proxy that has been applied to the mooring data I showed previously. These three sites are Southeast Alaska, Seward and Kodiak. These are projections that have been

applied to the morning data. In this case, the warm colors are acidified water. You can see that especially in Southeast Alaska, the warm colors emerge sooner, as soon as 2020, than they do at the other two sites. We know there are spatial variances. We are working hard to combine both of these things into a regional forecast model. [SLIDE ANIMATION] That modeling effort is being supported by the Arctic research program. This is just a brief output of what that looks like for the year 2009. You can see the cool colors are located near the shallower areas. On top of that, rather than just looking at the surface, the regional model cuts several layers in the ocean so we can understand the variability of depth.

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SLIDE 18: We also want to understand co-occurrence of ocean acidification with other stressors. Ocean acidification does not happen in a vacuum. What I show here is a snapshot of temperatures over the North Pole. This is from the Washington Post. As you may have heard, another extreme heat wave has struck the North Pole. [SLIDE ANIMATION] Scientists have never seen so little ice in the Bering Sea. The warm temperatures led to massive ice loss. [SLIDE ANIMATION] From NOAA's Annual Arctic Report Card, we know this is unlikely to abate. It is likely to continue in the future. Ice loss is just another major ecosystem stress. [SLIDE ANIMATION] We have multiple stresses, warm temperatures, ice loss, oxygen is getting depleted in water, and now we are just starting to deal with ocean acidification. If we are only focusing on ocean acidification, we are missing a much larger part of the story.

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SLIDE 19: We work closely with our partners to make sure we understand the ecosystem. This particular study incorporated several of the structures in a population metric, based on current management levels for crab history. If organisms cannot adapt to these simultaneous changes, ultimately the fishery could collapse. In particular, the challenge is understanding when impacts might emerge. If we understand ocean acidification is not happening, there is not a change in ocean. The model implies that the population is able to cope when that may not be true. If we assume ocean acidification is happening and it happens at a constant rate, population effects emerge much sooner in this model, and we may see impacts as soon as 2035. If we incorporate an nonlinear rate, that response may be delayed. However, it is important to remember, that if the response is delayed, it does not excuse us from needing to find the capacity to do something now. We need to start preparing for what that challenge might look like. Otherwise, if we wait until crisis happens, there is no opportunity to avoid it from a sustainable management standpoint.

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SLIDE 20: We have taken that risk to the red king crab fishery and combined it with other risks. We know that pollock are more resilient. Whereas crab is more vulnerable. We combine that with sociological data. It shows how much a community relies on fish, either to earn money for the local economy, or to get protein if they eat these fish primarily. What does a collapse in the population do? On top of that, this model asks whether or not communities have a diverse

enough economy that they can shift to finding other proteins or other jobs? The ecosystem vulnerabilities combined with the demographic data created a risk assessment for fisheries. The blue areas are better able to cope with ocean acidification. They are slightly more resilient. The area in yellow is moderate and the red areas are extremely vulnerable. Those areas are located along the coasts where fishing is one of the only jobs that you can get. And also small rural communities where fish form the primary source of protein.

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SLIDE 21: We know that it is likely that Southeast Alaska may struggle first. As I already pointed out, Southeast Alaska will experience ocean acidification sooner than the other sites. The duration of the acidified conditions increases much more rapidly than the other sites as well. If we choose a place to focus on, as one of the areas for ocean acidification, we might consider focusing on Southeast Alaska. That is the scientific perspective: What is happening, in terms of environmental changes? What risks do those changes pose? For the most part, scientists back off at this point and say further decisions are your responsibility. They back away from the community and decision-makers. I still think there is a role for us to play.

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SLIDE 22: Scientists can offer evidence-based perspectives on OA mitigation actions. One of the questions that I get the most often is can we grow seagrasses to combat ocean acidification? I'm glad I have a relationship with the local community that they know they can ask questions. The truth is that seagrasses and other phytoplankton soak up carbon dioxide during the day. If you think back to high school chemistry, they breathe carbon dioxide just like we breathe oxygen. The theory is that if you grow seagrasses, you might be able to pull carbon dioxide out of the system. However, we do not know if that will work yet. There is conflicting evidence from ongoing studies in Korea, Maine and Washington state. I want to stress that any positive impact is likely to be small and localized. The challenge is that any benefits seagrasses may have during the day may go away at night. They may also be taken away as ocean circulation happens. There may be no benefits, or nonlocal benefits. Growing seagrasses in and around your hatchery, may show benefits further away. Some studies show it may hurt the environment more than it helps, fostering bacteria that ultimately add more CO<sub>2</sub> to the water in your community. We are not sure the benefits will emerge. [SLIDE ANIMATION] Even if they do, it would take more than seaweed to deal with ocean acidification.

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SLIDE 23: By contrast, research indicates that one of the best things we can do to combat ocean acidification is to try to build broad resilience in the community. That is why I chose to frame this talk in this resilience framework. We want to make sure that we have a good relationship with the communities. And the communities have a good relationship with the decision-makers. So that when risks emerge, everyone has an opportunity to be on the same page. And everyone has an opportunity to communicate with each other about decisions. There are many scientists that are participating actively in this. The NOAA Ocean acidification Program and the Integrated

Ocean Observing System sponsored the Alaska Ocean Acidification Network. This is a regional network designed to connect scientists directly to stakeholders. I want to point out that these teams are not formed primarily of scientists doing public outreach. [SLIDE ANIMATION] They are formed from stakeholders in the community. We try to get scientists on these committees -- a few scientists on these committees, because we want to make sure the communities have the primary voice. In the Alaska Ocean Acidification Network, we have tribes for the Alaska shellfish, growers associations, tribes, small businesses etc. These are the people we want to communicate with. Actually, in Alaska, I feel it is one of the best regions in the country to work with. Alaskan communities are so close-knit already. They already have a resilient community structure.

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SLIDE 25: To put it simply, Alaska cares. All of these organizations that you see listed here have either helped us or communicated their priorities directly to us.

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SLIDE 26: Actually, if you do the research, ocean acidification awareness in Alaska is three times higher than the rest of the United States. It is documented research. Alaska is doing a really good job in hearing about ocean acidification and understanding ocean acidification .

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SLIDE 27: That awareness is working into the resilience framework. Some of us scientists are participating in AdaptAlaska, a program focused on climate change and developing climate resilience. Not just focused on ocean acidification. Also focused on coastal erosion. Things like ice loss, wildfires etc. By participating in the larger climate resilience efforts, we are doing a lot to take action already on climate change in Alaska. I was proud to be a small part of this. For those of you who are here in DC, tomorrow is the NOAA ceremony for winners of the Department of Commerce Bronze Medals for Exception Service.. Another member of the NOAA in the National Ocean Service, Amy Holman, was awarded a bronze medal for her participation in this program. Amy's citation specifically references her hard work connecting scientists, stakeholders and members of the community, to help communities achieve the goal of climate resilience in the future.

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SLIDE 28: Another action we are taking is our hatchery adaptation partnerships. We are working directly with small businesses to help monitor ocean acidification in the region. We have the Alutiiq Pride hatchery that is our longest partnership. We just started the partnership with Oceans Alaska, another shore based hatchery. We are working rectally with a tribe to monitor conditions in Sitka. Those are small businesses that are already taking action, based on their relationships with the Network.

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SLIDE 29: While those are some great knowledge-to-action, evidence-based strategies for building resilience, not everything paints as pretty a picture in Alaska. We are not ready to say,

you are resilient. Check the box and stop working on climate resilience in Alaska. This is the beginning of what will be complex processes that involve different voices and stakeholders. And a coproduction of knowledge. As a scientist, I can tell you how the environment is changing. I can tell you what the risks might be, but I do not know what that means for your group. I don't know what that means for your capacity to take action. Listening to local stakeholders is a big part of my job. So that I can come back and say, maybe if we put this here or I can write a grant to help with this spot of uncertainty. That is valuable to me also. Sometimes, the next step of the process is to not just take action, but to continue to explore hazards. I mentioned Alaska is big. Our capacity to make observations in Alaska because of that is limited. We have models and proxies to extend our observation, but making more observations is a big priority.

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SLIDE 30: I work with the technology development program that is trying to turn autonomous vehicles and to ocean acidification platforms . There able to elect more information without a human cost or human risk. The picture I am showing is a saildrone. It is 20 feet long and 20 feet tall. It is difficult to see scale from this image. Last year, we are able to put equipment on a saildrone to capture multiple different carbon parameters and turn the drone into a device that can measure ocean acidification in the future. The development is ongoing. I am proud to say that the saildrone tech development team also earned a 2016 Bronze Medal for Exception Service from the Department of Commerce.

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SLIDE 31: Going forward, we want to listen to the communities and understand what their priorities are in particular, one of the species we do not study that much is pink salmon. There are some colleagues at the University of Washington that are starting to study it. They are interested and prey quality and prey quantity. [*SLIDE ANIMATION*] But also in acidification-impacted olfactory responses and their capacity to migrate. They are just starting this research. We do not know exactly what is happening. We do know there olfactory system is kind of wonky. We are excited to continue that work.

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SLIDE 32: Those online, I wanted to show this side. I want you to be able to contact us if you have questions. Or if you want to talk again, I am happy to give this talk to a local organization as a webinar. We have the umbrella manager for the Alaska operations, which is Tom hurst. I am Dr. Jessica N. Cross, the primary observer for this program. Tom works on fish. Bob Foy works on crab. Bob Stone works on corals. Mike Dalton is the economic modeler.

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SLIDE 33: With that, I will close. I will look to the room moderator as we take questions.  
[Applause]

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Moderator: Are there questions in the room?

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Q: On your first slide, you showed the concentration of CO<sub>2</sub> . What evidence do you have?

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JNC: It has been well documented that the increase is associated with the industrial revolution from long time series measurements. If you're interested in learning more, I have plenty of resources I can share with you.

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Q: Why is the concentration of CO<sub>2</sub> naturally higher around Alaskan waters?

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JNC: Cold water holds more carbon dioxide naturally. There is a circulation pathway that connects all of the ocean. The water has traveled along the bottom for somewhere between 900 and 1100 years. Lots of matter has fallen through. As the organic matter is respired, it creates carbon dioxide. The net impact of all the respiration eventually ends up in the waters.

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Q: From the NOAA enterprise risk perspective, how is ocean acidification affecting NOAA programs ?

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JNC: I am not sure what you mean?

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Q: Is ocean acidification going to impact not sure -- national fisheries service? Will they go into their budget?

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From Libby Jewett, Program Director for the NOAA Ocean Acidification Program: We are just 13 to work on those ideas -- just starting to work on those ideas. We make measurements because we want to understand the impact on fisheries. We are just starting to get to the point where we are taking about evidence managed based programs. We want to manage fisheries in a sustained way. We want to understand how to do that. Throughout the ocean acidification programs -- programs by we are just getting to where we understand what that means. If you have questions about the budget associated with that, I would direct you to those working with the national fisheries service. We have a certification program with the atmospheric research program. It continues to be envisioned as a place where we integrate and correlate. We have money that comes in and out. We find the fishery service to do that. We are funding the national Ocean service to work on sanctuaries and modeling. We have money going to the OAR lab . We also leverage and there is a whole part of it that focuses on fisheries. Several employees are doing the research. It is coordinated and is an integrated effort.

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Q: From the NOAA enterprise risk perspective, do you see this will be such a big problem that NOAA will have to focus and take resources away from other programs and apply it?

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Libby Jewett: It has not happened yet.. Congress has in -- we are leveraging. There is so much we do not know about the vulnerabilities. It is hard to imagine putting all this money into ocean acidification work. It is definitely important . We will see.

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Moderator: We have a few questions online. This is a multitiered one. Is there anything that the inland states fish and consumer can do to help?

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JNC: Is there anything that inland states fish and shellfish can do to help? The first thing is to educate yourself to understand that ocean acidification has the potential to impact you. For the cost of fish and shellfish that you eat in restaurants. Supporting ocean acidification research and research in general is important. I would also say, that the next thing you could do is to talk to your local community. About what climate risks you are facing. Even if ocean acidification is not a big interest in for example, Kansas. There are things you are expressing.

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Moderator: Is it possible to create a route to recover those on edible shells?

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JNC: I am not sure which shells you are referring to? I will assume pteropods . Or -- if you're talking about old shellfish or crab shells or something to create buffering capacity to create resilience to ocean acidification, just like growing seagrass, it has the potential for a small overall effect. It will be spread out over a long time. The cost associated with that is high. We do not want to focus on that as a cost effective opportunity to mitigate ocean acidification.

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Moderator: He was discussing oysters. Can big multinational seafood industry do more or do something?

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JNC: Yes, multinational industry can be a part of this process. I would highly encourage you to talk to the ocean acidification network. We have subgroups as part of the network. They are interested in grant writing and funding for ocean observation. Commercial industry has the opportunity to go out and collect data. Because you fish commercially. Those who have the opportunity to collect measurements, we would love the opportunity to talk about it. I will say, we have a limited supply of equipment. The best investment you could make is to partner with us.

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Moderator: They are not familiar with the Omega figure in your slides. What does it translate to in pH? The CO<sub>2</sub> went up in five years.

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JNC: You are talking about the Omega figure. The question in particular is essentially about what is Omega and how do you translate? One of the most common variables we use for

studying OA is called the calcium carbonate saturation state, often symbolized as Omega. A low omega value indicates the potential for calcium carbonate to dissolve. A shorter way of saying that is that a low omega value indicates corrosive water.

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Moderator: Do we know how rapidly ocean acidification is happening in Alaska?

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JNC: The timeseries we have collected so far has only been for a couple of years. We know at this point, undersaturated one -- water with low Omega value-- corrosive water that is likely to dissolve carbonate minerals-- is already present. . We have already made observations that show something is dissolving. Even if we do not know what it is. There is no marker for each molecule of extra calcium. And which one is coming from a particular source. They all look the same. And so, we know as a baseline, OA is likely to be having those impacts. As for how fast it is changing, there is spatial variability around Alaska. Southeast is changing faster than other areas, as I showed.

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Moderator: Are there -- are the additional ice free days creating additional challenges in observation?

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JNC: Are additional ice free days providing challenges to observing? When you go out on ships, you have to plan in advance. When something big happens, like the ice melt did in February, there is not the capacity for us to be able to respond. We cannot be there to capture the signal because we have to plan too far in advance. The biggest observational challenge is to get out there and respond to this adaptively with agility. We want to be able to meet the signals when they start to happen. New technology will be a big part of that. Being agile -- once the drone is more highly developed we would like to launch that as soon as it is safe every year. Rather than having to plan years in advance. We are working hard to make sure we are able to design an observing system that has a rapid response.

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Moderator: Last online question: it does not sound like there is a solution to the issue. The prognosis is to adapt to the change that is to come from ocean acidification .

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JNC: Sometimes it does not sound like there is a solution. Sometimes, when I give this talk, I say we have the opportunity to do something and see what happens. We have the opportunity to adapt by building resilience. Or we have opportunity to do nothing and suffer the consequences. We want to make sure that rather than just seeing what happens or deciding we are comfortable suffering, we give the communities who are at a high risk the opportunity to adapt. I want to make it clear that there are winners and losers. It is not that all Alaskan fishermen should get out of the business now. That is not what I am saying. Please do not take that soundbite out of

context. That is not what I am saying. It may be for example, you switch to a different fish. We will still have fish. It may be we are able to safely manage the fisheries through ocean acidification, and we are able to continue to harvest the same fish. It may be that we have to change the location where we fish. Some populations may be threatened, whereas others are okay based on their specific vulnerability. In order to find out those answers and create sustainable management around fisheries, we have to understand all facets of this problem. We have to link the science up to a human system. That is one of the places, at least in terms of the science entity, we try to coproduce the knowledge. We would not be able to do it without you guys telling us your priorities. And vice versa.

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Moderator: Are there any more questions?

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Moderator: Thanks for joining us. [Applause]

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JNC: I will make one more pitch for the Alaska Ocean Acidification Network. It is run by the Alaska Ocean Observing System. Email if you want to get involved.

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Moderator: Thank you.